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Original Communication

Diagnostic accuracy of heel pad palpation – A phantom study

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Abstract

Falanga torture involves repetitive blunt trauma to the soles of the feet and typically leaves few detectable changes. Reduced elasticity in the heel pads has been reported as characteristic sequelae and palpatory testing of heel pad elasticity is therefore part of medicolegal assessment of alleged torture victims.

The goal was to test the accuracy of two experienced investigators in determining whether a heel pad model was soft, medium or hard. The skin-to-bone distance in the models varied within the human range.

Method: Two blinded investigators independently palpated nine different heel pad models with three different elasticities combined with three different skin-to-bone distances in five consecutive trials and categorized the models as soft, medium or hard.

Results: Two experienced investigators were able to identify three known elasticities correctly in approximately two thirds of the cases. The skin-to-bone distance affected the accuracy.

Conclusion: The use of clinical examination in documenting alleged exposure to torture warrants a high diagnostic accuracy of the applied tests. The study implies that palpatory testing of the human heel pad may not meet this demand. It is therefore recommended that a device able to perform an accurate measurement of the viscous-elastic properties of the heel pad be developed.

Keywords: Torture; Falanga; Heel pad; Palpation; Clinical examination

1. Introduction

Torture is practiced systematically in more than half of the countries of the world.[1] The applied torture methods are often directed towards the musculoskeletal system aiming at producing pain and injuries in the soft tissues. Characteristically, these types of torture leave relatively few findings despite subsequent and frequently severe chronic physical disability.[2] There is therefore a need for validated examination methods, which can be used for medicolegal purposes and as important tools in the prevention of torture. We have chosen to focus on the heel pad as a potential locus for documenting findings consistent with allegations of torture.

The human heel pad is a complex structure consisting of a fat pad with micro- and macro-chambers divided by an intricate fibroelastic septation. The fat pad is contained by the internal heel cup, a ligament that encircles the fat pad as a functional link between the septal structure and the subcutaneous tissue. The structure of the septation is designed to avoid any outflow of fat from single compartments and hence they are resistive to compressive loads.[3,4]

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The heel pad presents non-linear visco-elastic characteristics, as the majority of soft body tissues. The term viscous implies that it deforms as a function of time under a given load, and the elastic term that once the deforming load is removed, the tissue returns to its original configuration. Visco-elastic materials have the ability to absorb energy and thus to reduce the magnitude of impact forces by extending the time course of the impact event. In the heel pad, the viscous and elastic features correspond to the fat cells and septa, respectively. Trauma to the heel pad may result in destruction of the complex structure with resulting permanent impairment of its function as a shock absorber.[5,6]

Falanga torture involves repeated applications of blunt trauma to the soles of the feet including the heel pads resulting in permanent changes with impaired gait and chronic pain.[7,8] The aetiology and pathogenesis of the persistent pain and disability seen after falanga torture is not fully understood though several theories have been put forward based on clinical observations. One of the characteristic permanent changes reported at clinical examination is the flattened shape of the loaded heel, which is believed to be caused by a destruction of the intricate septation with resulting medial and lateral displacement of the fatty tissue of the heel pad.[9] At palpation, the calcaneus is more easily felt under the skin, so the heel pad feels too soft.

We have undertaken a project to develop a device, which measures the elastic properties of the heel pad. In this project, we have made a heel pad model with different elasticities to test the device. This heel pad model also makes it possible to test the human ability to determine the elastic properties of a tissue by palpation and thereby establish whether there is a need for a measuring device.

The goal of this study was to test the accuracy of two experienced investigators in determining whether a heel pad model was soft, medium, or hard. As a confounding factor we varied the skin-to-bone distance within the human range.

Materials and methods

The mould

The heel pads used in this study were created by embedding part of an artificial calcaneus in an elastic material by use of a mould (Fig. 1). The mould consists of a 55 mm high plexiglas cylinder with an inner diameter of 50 mm. The cylinder is closed with a plexiglas plate at the top and bottom. To mimic the tuberosity of the calcaneus bone, a plastic calcaneus (AMS Superbones, Washington, USA) facing upwards was placed on a pedestal that was in turn attached to the bottom plate. By varying the height of the pedestal, different skin-to-bone distances were made.

PVA cryogel

The heel pad was modelled by use of a particular viscous liquid composed of 10% of polyvinyl alcohol (PVA) dissolved in water-based material. It provides an excellent model of the human tissue since the elastic modulus of PVA cryogel is controllable by varying the number of freeze/thaw cycles or the PVA concentration. Bought as a liquid, PVA cryogel changes into a gel by a freeze/thaw process.

Skin-to-bone distance

From eleven papers describing unloaded heel pad thickness, we calculated the mean (M) skin-to-bone distance to 17 mm with a standard deviation (SD) of 3 mm (Table 1). In the present study, we used three skin-to-bone distances:

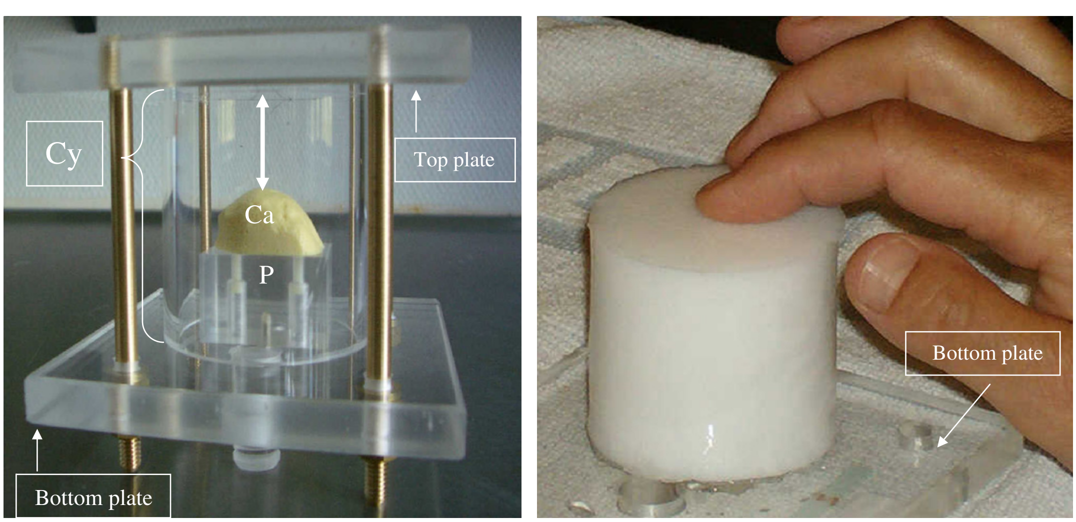

Fig. 1. Heel pad model. Left: Mould for the heel pad model. Inside the cylinder (Cy), the plantar part of the plastic calcaneus (Ca) is mounted upside down on the pedestal (P). The pedestal is attached to the bottom plate. The double arrow indicates the skin-to-bone distance. The top and bottom plates close the cylinder. Right: The heel pad model has been taken out of the cylinder and is still attached to the bottom plate. It is opaque and the calcaneus cannot be seen.

$M - SD$, M, and $M + SD$, i.e., 14 mm, 17 mm, and 20 mm, respectively.

Selection of elasticity

Twelve cryogel cubes (three of each) were made with one through four freeze/thaw cycles – each cycle making the sample harder. The test specimens were cuboids with nominal side lengths of $20 \times 20 \times 40$ mm. Some shrinkage occurred in each freeze/thaw cycle. The elasticity of the samples was measured by compression testing applying an Instron test machine with a 250 N load cell. The strain rate was $0.0025\ s^{-1}$ and the longitudinal and transversal strains were measured with a video extensometer. Moduli and ratios hereby found are shown in Table 2.

Elastic moduli of foot pad tissue in the range from 24 kPa to 306 kPa have been reported.[16,21,22] The PVA samples match this range well.

Two experienced physicians selected the cubes made with two, three, and four freeze/thaw cycles as representative of the human range of heel pad elasticity, i.e., soft, medium, and hard. The three different elasticities combined with three different skin-to-bone distances gave nine different heel pad models.

Palpation tests

Two investigators (KA and BDS) palpated the models in five consecutive trials each. Each trial consisted of palpating the model n times. In each trial we wanted the probability of guessing a model correctly all n times to be less than 0.05. Since, the chance of guessing correctly is 1/3 at each palpation, n became three ($1/3^3 < 0.05$). A trial therefore consisted of 27 palpations of the nine models in a random order (as each model had to be palpated three times).

A wide area of the examination table was covered and the investigator could not see how many models existed. The investigators were told that each model contained a calcaneus and that the models were soft, medium, or hard. They were not informed that the skin-to-bone distance varied. The investigator was allowed to familiarize herself with one model to get to know the shape. She was not told whether it was soft, medium, or hard. She was then blindfolded and given the models in a predefined computer-generated random order. There was no time limit. The investigator had to categorize each model as soft, medium or hard. There was a 30 min break between trials.

After three trials, the investigator was shown the nine models and was explained about the different skin-to-bone distances. She was allowed to familiarize herself with the nine models. She then performed two more trials blindfolded.

Table 1
Skin-to-bone distance from eleven studies

Author	Year	Technique	Thickness range (mm)	Mean ± SD (mm)
Gooding GA et al.[10]	1985	Ultrasound	13–21	16.6 ± 0.32
Jorgensen U[11]	1989	Radiography	12.5–30	17.4 ± 3.7
Prichasuk S et al.[12]	1994	Radiography	12–28	18.70 ± 2.46
Prichasuk S[13]	1994	Radiography	14–27	18.77 ± 2.33
Hsu TC et al.[14]	1998	Ultrasound	Na	17.6 ± 2.00 20.10 ± 2.40
Rome K et al.[15]	1998	Ultrasound	9.9–17.1	12.47 ± 4.22
Gefen A et al.[16]	2001	Radiography	Na	12.5 ± 0.20
Kanatli U[17]	2001	Radiography	Na	19.55 ± 2.52
Nass D et al.[18]	2001	Ultrasound	Na	15.0 ± 2.6
Tong J et al.[19]	2003	Ultrasound	9.8–18.7	15.5 ± 2.4
Ledoux WR et al.[20]	2004	Radiography	Na	17.10 ± 3.63
Overall				17 ± 3*

Na = not available, * the studies have equal weight in the overall value.

Table 2
Elasticity and freeze/thaw cycles

Freeze/thaw cycles	Elastic modulus (kPa)	Poisson's ratio
1	18	0.54
2	64	0.49
3	127	0.52
4	161	0.53

Statistics

We tested the *independent* accuracies of the two investigators in the five trials based on the proportion of correct answers (%), with an emphasis on the elasticities applied, enabling estimation of the difference between these. The null-hypothesis was two fold: that there were no differences between trials or elasticities. We applied the Cochran Q-test for homogeneity,[23] and evaluated the amount of heterogeneity on the basis of I^2.[24] These differences between trials and elasticities were combined based on an empirical Bayes methodology, applying the method of moments estimator proposed by DerSimonian and Laird[25] using Review Manager (RevMan version 4.2 for Windows, Copenhagen, Denmark). We used the total dataset for each investigator (135 binomially distributed yes/no test samples per assessor) to estimate the overall accuracy for each investigator. We calculated the 95% confidence intervals (CI) based on 10,000 bootstrap samples – allowing us to estimate the median (proportion of correct answers), and the corresponding 2.5th and 97.5th percentile of the bootstrapped empirical data distribution.[26]

If there was no difference between the two investigators over the five trials, or over the three elasticities the pooled results (270 observations) would be used for an analysis of the interaction between skin-to-bone distance and elasticity applying a standard χ^2-test (with four degrees of freedom; elasticity $\times$ skin-to-bone interaction). Except for the homogeneity and *empirical Bayes* analysis, the SAS® statistical package (SAS 9.1.3 executing on the XP PRO platform; Copyright [c 2002–2003 by SAS Institute Inc., Cary, NC, USA) was used for all statistical analyses.

Results

Performance by trial

The two investigators performed almost identically with approximately 2/3 correct answers (Fig. 2 Left), with the following proportions correct for KA and BDS: 67% (bootstrap 95% CI: 56–78%) and 66% (54–77%), respectively. As presented in Fig. 2, there was no difference between the percentage correct answers between assessors across trials ($P = 0.91$; $I^2 = 0\%$); the combined difference between percent correct answers was +1%-point (95% CI: –10% to +12%-point). The performance did not improve when the investigators knew about the varying skin-to-bone distance and had become familiar with the nine models (trial 4 and 5).

Performance by elasticity

The two investigators had a very similar performance with the lowest accuracy in the soft models, slightly higher accuracy in medium models and highest accuracy in hard models (Fig. 3). There was no difference between the percentage correct answers between assessors across elasticity ($P = 0.25$; $I^2 = 28.8\%$); the combined difference between proportions was –1%-point (95% CI: –13% to +10%-point).

Performance by skin-to-bone distance

There was a significant elasticity skin-to-bone interaction ($P = 0.0003$), suggesting that a clinical assessor's ability to answer correctly varies across elasticity × as the skin-to-bone distance changes (Fig. 4). A superficial bone position (14 mm) made it easier to correctly identify a hard model; whereas, a deep bone position (20 mm) made it more difficult to identify a hard model correctly. Exactly opposite findings were made in soft models. In medium models, the intermediate bone position gave highest accuracy.

Discussion

The study showed that two experienced investigators had almost identical performance in determining whether a heel pad model was hard, medium, or soft. Their accuracy of two thirds is double that of chance and is not impressive considering the medicolegal use of heel pad palpation in the evaluation of alleged falanga torture victims.

By using a heel pad model with a known and controllable elasticity, we had the unique opportunity to accurately test the human ability to classify into soft, medium and hard by means of palpation. We made it easy for the investigators by creating a very primitive model with only one type of "tissue" in comparison to the complex structure of the human heel pad with skin, subcutaneous connective tissue, and the complex structure of the heel pad itself with septation and spiral structure of chambers with fat. Our very limited number of classes (soft, medium, hard) further made it easy for the investigators in comparison to the continuous variation in the human heel pad elasticity. We therefore expect that our investigators will have a lower accuracy in a human material and the observed accuracy of two thirds should be seen in this context.

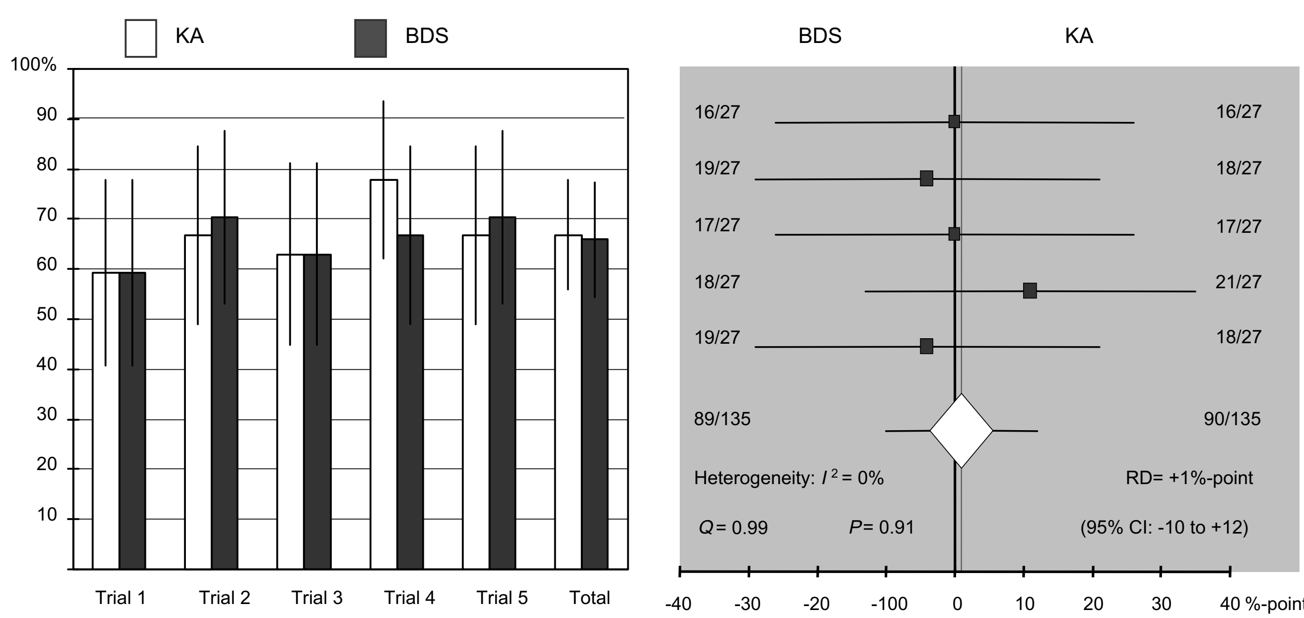

Fig. 2. Performance of the two investigators in the five trials. Left: The bars show the percentage of correct answers for both investigators through trials one to five (with 95% CI). The bars marked total are the overall percent correct answers (with empirical 95% CI) for each assessor, based on the bootstrapped median and the 2.5th and 97.5th percentiles. Right: The differences between trials were combined based on an empirical Bayes methodology and the amount of heterogeneity was evaluated on the basis of I^2. The data consistently show that the investigators perform better than chance only and that they agree.

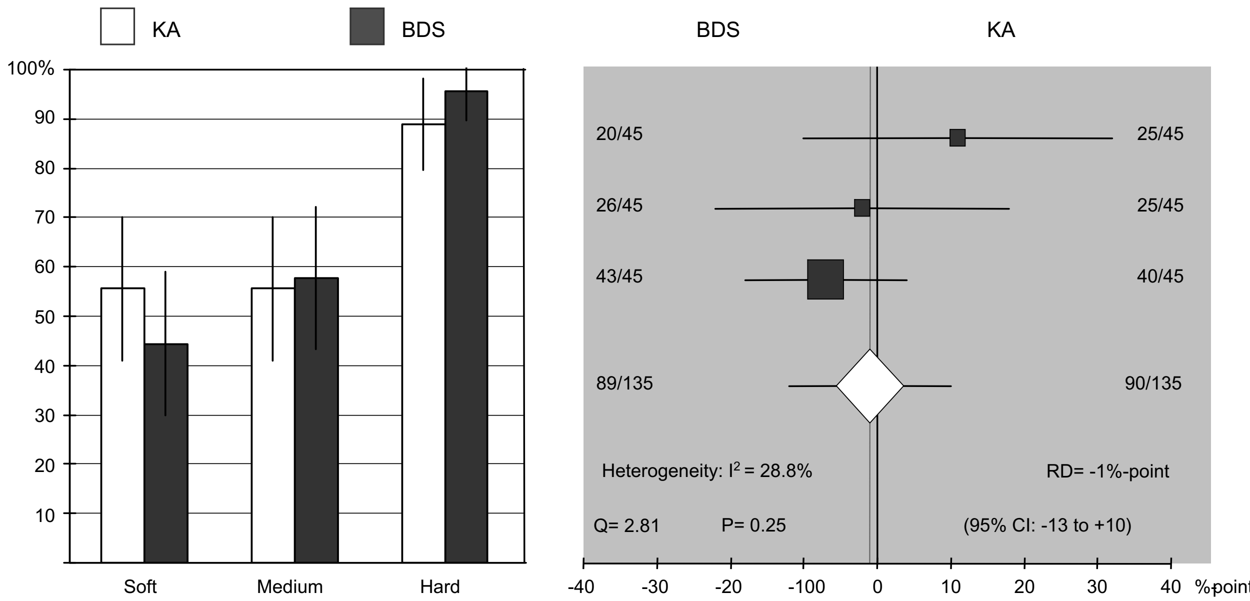

Fig. 3. Performance of the two investigators by elasticity. Left: The bars show the percentage of correct answers for both investigators by elasticities soft to hard (with 95% CI). Right: The differences between elasticities were combined based on an empirical Bayes methodology and the amount of heterogeneity was evaluated on the basis of I^2. The data consistently show that the investigators perform better with increasing hardness and that they agree.

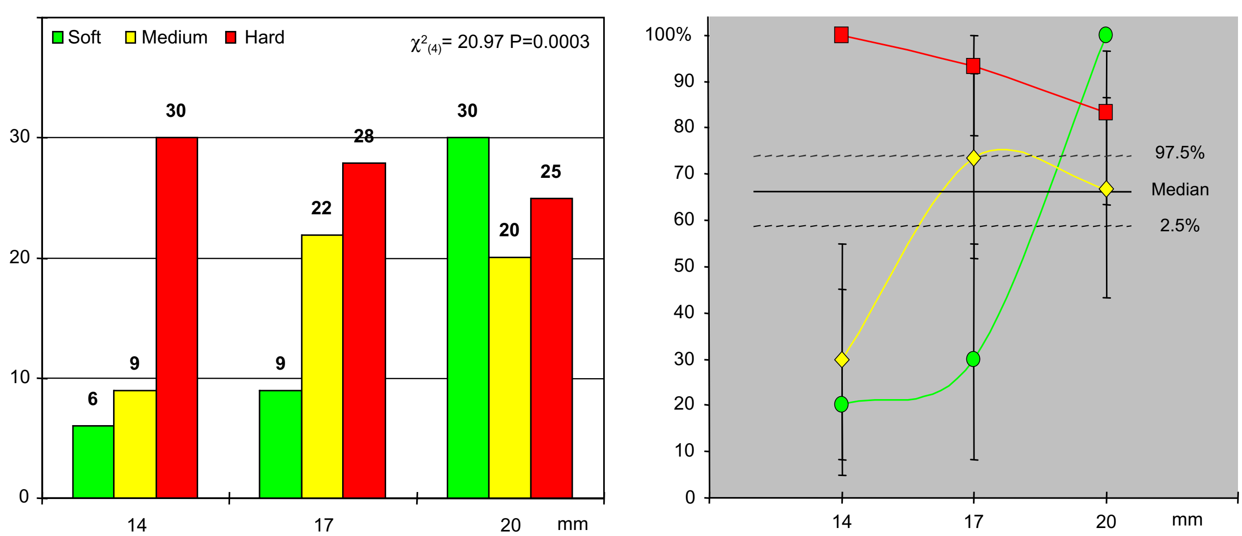

Fig. 4. Combined performance over elasticities and skin-to-bone distances. Left: The absolute number of correct answers for each elasticity is presented by skin-to-bone distance. Because of the agreement (Figs. 2 and 3), the results were pooled in order to evaluate this interaction. Right: The three coloured graphs present the three elasticities plotted against the skin-to-bone distance. Each elasticity has its own pattern as skin-to-bone distance varies. E.g., a superficial bone makes the model feel harder and vice versa for a deep bone. The horizontal line marked median is the overall percent correct answers (with empirical 95% CI) across assessors, based on the bootstrapped median and the 2.5th and 97.5th percentiles.

The variation in skin-to-bone distance made the models slightly more realistic although the variation again was discontinuous with only three classes exemplifying the human mean ± SD. When the bone was close to the skin, the model felt harder resulting in 100% accuracy for the hard model with smallest skin-to-bone distance. Likewise, when the bone was deep, the model felt softer leading to 100% accuracy for the soft model with highest skin-to-bone distance. It was interesting that the investigators did not improve their performance when this variation was known and they had familiarized themselves with the models. We postulate that this will also be the case when the human heel pad is palpated: we know there is a variation in the skin-to-bone distance, which will affect our impression of hard versus soft just as the elasticity itself, but we do not know the individual skin-to-bone distance.

We believe there is a need for a device capable of measuring the elastic properties of the heel pad in order to obtain more credible evidence in the evaluation of alleged falanga torture victims. Theoretically, the device could

record force and displacement when pressed against the heel pad. A series of corresponding force and displacement recordings during compression and decompression will allow us to measure the elastic properties of the heel pad. However, also this device will need to take in to account the variation in skin-to-bone distance. This is because the elastic nature of any tissue will change dramatically toward hard when a certain degree of compression has been reached. Therefore, we need to find an algorithm for the influence of skin-to-bone distance upon force-displacement data in order to allow for comparison between subjects with different skin-to-bone distances. This distance could be obtained with ultrasound.

Conclusion

The use of clinical examination in documenting alleged exposure to torture warrants a high diagnostic accuracy of the applied tests. Our study implies that palpatory testing of the human heel pad may not meet this demand.

Two investigators experienced in evaluation of heel pads in torture victims had an accuracy of approximately two thirds when palpating and classifying simple cryogel heel pad models as being soft, medium or hard. The variation in skin-to-bone distance in the models highly influenced the results. We recommend that a device able to perform an accurate measurement of the visco-elastic properties of the heel pad be developed. Such a device needs to take the individual skin-to-bone distance into account

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Roles: STP was chief investigator and guarantor, responsible for literature search, study design, data collection, data analysis, drafting, revision, and final approval. SM was responsible for literature search, model development, elasticity measurements, study design, data collection, data analysis, drafting, revision, and final approval. JW was responsible for model development, elasticity measurements, study design, data collection, data analysis, drafting, revision, and final approval. KA was responsible for data collection, revision, and final approval. BDS was responsible for data collection, revision, and final approval. JIB was responsible for elasticity measurements, revision, and final approval. RC was responsible for study design, data analysis, drafting, revision, and final approval.

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